Oxygen Therapy

Description and Advances in Oxygen Delivery Systems

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Abstract

The Experimental Diving Unit (EDU) of Defence R&D Canada – Toronto has received support from the Search and Rescue (SAR) New Initiative Funds (NIF) to develop and recommend a system for providing oxygen to multiple victims. Current breathing systems used for oxygen therapy are highly inefficient in the consumption of oxygen, especially when a mass casualty incident is involved. Treating more survivors means more oxygen must be transported which increases weight, volume and risk. There are many breathing systems on the market for oxygen therapy. These respirators vary in the concentration and quantity of oxygen effectively delivered to the patient. The present report defines and describes oxygen therapy, including an introduction to human respiratory physiology and a review of the characteristics and capabilities of breathing systems that are the most commonly utilized to provide oxygen. The purpose is to identify promising solutions for the Canadian Forces search and rescue operations.

Résumé

L'Unité de plongée expérimentale (UPE) de R & D pour la défense Canada – Toronto a reçu l'appui du Fonds des nouvelles initiatives (FNI) du Secrétariat national de recherche et de sauvetage (SNRS) afin de mettre au point et de recommander un système permettant d'administrer de l'oxygène à de nombreuses victimes. Les systèmes de respiration actuels utilisés en oxygénothérapie sont extrêmement inefficaces sur le plan de la consommation d'oxygène, en particulier en cas d'incident entraînant des pertes massives. Pour traiter un plus grand nombre de survivants, il faut pouvoir transporter une plus grande quantité d'oxygène, ce qui contribue à accroître le poids, le volume et le risque. Un vaste éventail de systèmes de respiration sont offerts sur le marché pour l'oxygénothérapie. Les différences entre les appareils concernent la concentration de l'oxygène et la quantité d'oxygène effectivement administrée au patient. Dans le présent rapport, nous définissons et décrivons l'oxygénothérapie, nous présentons des notions élémentaires de physiologie respiratoire humaine et faisons un survol des caractéristiques et des possibilités des systèmes de respiration qui sont les plus couramment utilisés pour administrer de l'oxygène. Nous nous proposons d'identifier les solutions prometteuses pour les opérations de recherche et sauvetage des Forces canadiennes.

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Executive summary

Current breathing systems used for normobaric[1] oxygen (O_2) therapy are highly inefficient in the consumption of oxygen, especially when a mass casualty incident is involved. For example, a non-rebreathing mask (NRM) with a Jumbo D cylinder (640 litres) commonly used in first-aid oxygen therapy provides 38 minutes of O_2 breathing to only one patient at a flow rate of 15 litres per minute (900 litres/hour) while the single pack of the Scott Aviox® emergency oxygen system, currently used by the Canadian Forces Search and Rescue technicians (CF SAR techs), lasts only 20 minutes. Furthermore, the patient uses only about two percent of the delivered O_2. The rest is exhaled into the atmosphere. This may be acceptable for treating accident victims in urban areas; but, to treat survivors in a remote area means more oxygen must be transported which increases weight, volume and risk to unacceptable levels. The Experimental Diving Unit (EDU) of Defence R&D Canada – Toronto has received support from the Search and Rescue (SAR) New Initiative Funds (NIF) to select, evaluate and recommend a system for providing oxygen efficiently to multiple accident victims using the current capacity of oxygen supplies. A wide variety of oxygen delivery systems are available on the market. These respirators can be open or closed circuit with continuous or on demand flows. They essentially vary in the concentration (from 24 to almost 100%) and quantity of oxygen effectively delivered to the patient. Most of the open circuit systems are unable to provide high-concentration oxygen and in many cases allow a very limited time on oxygen. When oxygen is available in quantities and its supply is not an issue such as in a medical centre, open circuit systems are preferred because of their simplicity and low cost. Demand systems and recently, closed circuit breathing units are becoming the first choice in remote areas where O_2 supplies are very limited. This report presents and reviews the state-of-art to identify promising solutions for the Canadian Forces search and rescue operations.

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[1] Normobaric oxygen therapy is the administration of oxygen to a patient at or near sea level pressure.

Sommaire

Les systèmes de respiration actuels utilisés pour le traitement par l'oxygène (O_2) normobare[2] sont extrêmement inefficaces sur le plan de la consommation d'oxygène, en particulier en cas d'incident entraînant des pertes massives. Ainsi, un masque sans réinspiration avec bouteille d'oxygène type grand format « D » (640 litres), couramment utilisé pour l'oxygénothérapie dans le cadre des premiers soins, permet d'administrer de l'O_2 à un seul patient pendant 38 minutes à un débit de 15 litres par minute (900 litres/heure), alors qu'un système autonome d'alimentation en oxygène d'urgence de type Scott Aviox, actuellement utilisé par les techniciens en recherche et sauvetage (Tech SAR) des forces canadiennes (FC), ne permet qu'une administration de 20 minutes. En outre, le patient n'utilise qu'environ 2 % de l'O_2 administré; le reste est expiré dans l'atmosphère. Ce type d'appareils peut être acceptable dans le traitement de victimes d'accidents en zones urbaines; toutefois, pour traiter des survivants dans une région éloignée, il faut pouvoir transporter une plus grande quantité d'oxygène, ce qui contribue à accroître le poids, le volume et le risque à des niveaux inacceptables. L'Unité de plongée expérimentale (UPE) de R & D pour la défense Canada – Toronto a reçu l'appui du Fonds des nouvelles initiatives (FNI) du Secrétariat national de recherche et de sauvetage (SNRS) afin de choisir, d'évaluer et de recommander un système permettant d'administrer efficacement de l'oxygène à de nombreuses victimes d'accidents en utilisant la capacité actuelle d'approvisionnement en oxygène. Un vaste éventail de systèmes d'alimentation en oxygène sont offerts sur le marché. Ces appareils d'assistance respiratoire peuvent être à circuit ouvert ou fermé, à débit continu ou à la demande. Les différences entre les appareils concernent essentiellement la concentration de l'oxygène (de 24 % à près de 100 %) et la quantité d'oxygène effectivement administrée au patient. La plupart des systèmes à circuit ouvert ne peuvent dispenser d'oxygène à forte concentration et, dans nombre de cas, offrent une alimentation en oxygène d'une durée très limitée. Lorsque l'oxygène est disponible en abondance et que l'approvisionnement ne pose pas de problème, par exemple dans un grand centre médical, les systèmes à circuit ouvert sont privilégiés en raison de leur simplicité et de leur faible coût. Les systèmes à la demande et, depuis peu, les systèmes de respiration à circuit fermé sont l'option à privilégier en régions éloignées, où l'approvisionnement en O_2 est très limité. Dans ce rapport, nous présentons et examinons l'état actuel des connaissances qui permettra d'identifier les solutions prometteuses pour les opérations de recherche et sauvetage des Forces canadiennes.

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[2] L'oxygénothérapie normobare consiste à administrer de l'oxygène à un patient à une pression égale à la pression atmosphérique (pression au niveau de la mer) ou proche de celle-ci.

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The author wishes to acknowledge the valuable assistance and helpful comments provided by Dave Eaton.

1. Introduction

The air we breathe contains 21% oxygen (O_2), 78% nitrogen (N_2) and 1% of other gases. Oxygen is a colourless, odourless and tasteless gas that is essential for the body to function properly and survive.

Oxygen therapy is a medical treatment in which supplemental oxygen, at concentrations greater than the surrounding air, is provided to the patient for respiration. It is often used to treat medical conditions such as hypoxia, chronic lung disease or traumatic injuries. There are three forms of oxygen therapy presently in use:

- Normobaric oxygen (NBO), also called surface or sea level oxygen, is the administration of supplemental oxygen (24 to 100%) at **atmospheric pressure**. Examples of medical conditions include asthmas, congestive heart failure, pulmonary oedema or as a first-aid treatment in search and rescue operations. It is also used for anaesthesia during surgeries.

- Hyperbaric oxygen (HBO): In this treatment, 100 % oxygen is breathed at **elevated pressure**. It is an essential treatment in many conditions, including decompression illness, carbon monoxide poisoning, burns and mountain sickness.

- Hypobaric or "altitude" oxygen: Because of the physiological limitation of humans when operating at altitude, they require an O_2 concentration greater than that inspired at sea level to prevent hypoxia.

A wide variety of oxygen delivery systems are available. These systems can be open or closed circuit with continuous or on demand flows. They essentially vary in the concentration and amount of oxygen to be effectively delivered to the patient. The present report is organized as follows. Firstly, the basis of human respiratory physiology will be introduced. Then, it is followed by a description of oxygen breathing systems, including a review of the existing oxygen supply systems as well as delivery units for breathing and non-breathing patients. The report reviews the characteristics and capabilities in regards to the possibilities for use by SAR techs to provide oxygen therapy to multiple casualties in remote areas.

2. Respiration

2.1. Physiologic Basis

The human body requires oxygen for metabolism. Indeed, oxygen is used to convert food into heat and energy. Therefore, the body needs oxygen to survive and the process of providing oxygen to a body is known as respiration.

Each breath fills the lungs with fresh air through respiratory airways, from the nose and mouth down to the alveoli (Fig. 1). The lungs include more than 100 million tiny sacs known as alveoli that inflate at every inspiration.

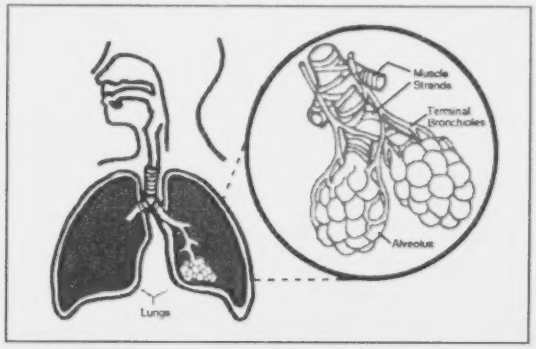

Figure 1. *Anatomy of the lungs [1].*

The extremely thin membranes (0.5 micrometre in average [2]) of the inflated alveoli allow, as illustrated in Figure 2, gaseous exchange between the alveolar gases and the blood that circulates in microscopic lung blood vessels. The "oxygenated" blood is constantly transported, from the lungs to every cell in the body for metabolism. The carbon dioxide generated by the cells while oxygen is metabolized is continually carried by the blood back to the lung and exchanged to the alveoli and then expired. The process of inhaling fresh air (with high O_2 and low CO_2 concentrations) and expiring used air (with high CO_2 and low O_2 concentrations), known as breathing, must be continuous to sustain life because of the body's inability to store oxygen and carbon dioxide over a long period.

For its proper operation the process of respiration (which is illustrated in Fig. 2) is "managed" through three major mechanisms:

1. **Respiratory system:** The primary function of the respiratory system is to obtain oxygen for use by the tissues of the body and eliminate carbon dioxide that the body's cells produce. This system includes the respiratory airways (nasal passages,

mouth, trachea and bronchial tubes), the lungs and the diaphragm (Fig.1). The respiratory gas reaches the lungs through the airways.

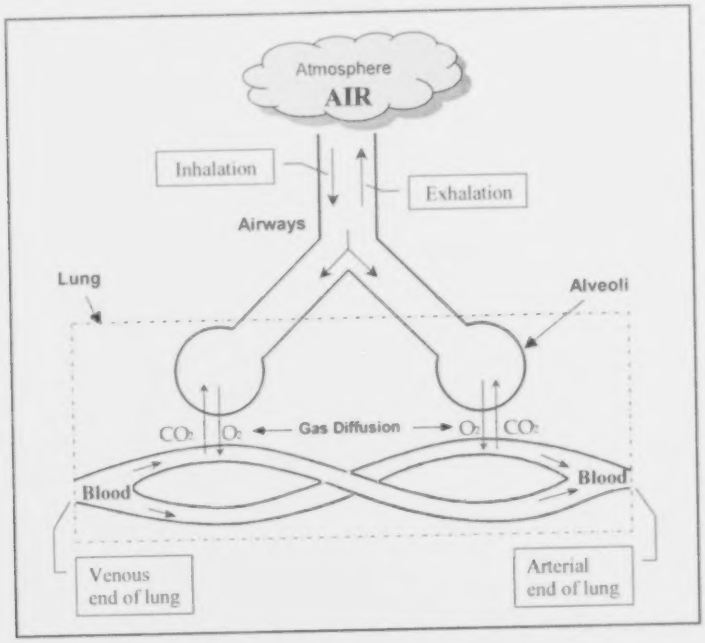

Figure 2. *Respiration process.*

In the lung, the alveoli must be ventilated to keep gas concentrations at levels allowing gas exchange with the blood. In this regards, three parameters have been found to be important [2] for pulmonary ventilation: (1) *Minute respiratory volume* ($\dot{V}_E$), also called minute ventilation determines the total volume of fresh air exhaled each minute. It is defined as the product of the respiratory frequency (f_b) in breaths/min and the tidal volume (V_T) in volume/breath (approximately 500 ml for a resting person): $\dot{V}_E = V_T \times f_b$; (2) *alveolar ventilation* ($\dot{V}_A$) is the rate at which the air in the alveoli is being renewed each minute. This parameter is important because it quantifies the volume of fresh air that participates in the gas exchange with the blood; (3) *dead space ventilation* ($\dot{V}_D$) is the rate at which the air in the anatomical dead space is being renewed each minute. The dead space is the volume of the respiratory airways not participating in the gas exchange (approximately 150 ml for a normal person).

$$\dot{V}_E = \dot{V}_A + \dot{V}_D$$

With each breath, the volume in the dead space is first moved into the alveoli before fresh air enters. In other words, the alveolar volume is the tidal volume

minus the dead space volume. This yields an alveolar volume of 350 ml for a normal adult.

2. **Gas Diffusion:** Gas exchange between the alveoli and the blood in the lung occurs by diffusion. This process requires a partial pressure (or concentration) gradient (as shown in Fig. 3). For instance, to diffuse oxygen from the alveoli into the blood, PO_2 must be higher in the alveoli than in the blood. Carbon dioxide, as opposed to O_2, diffuses from the blood into the alveoli; which means, PCO_2 must be kept higher in the blood than in the alveoli. Figure 3 and Table A1 in Annex A compare and summarize partial pressures of respiratory gases from inhalation to expiration at sea level. Similarly, Table A2 in Annex A presents partial pressures of O_2 and CO_2 in the lung blood before and after gaseous exchange and in the tissue capillaries before and after metabolism.

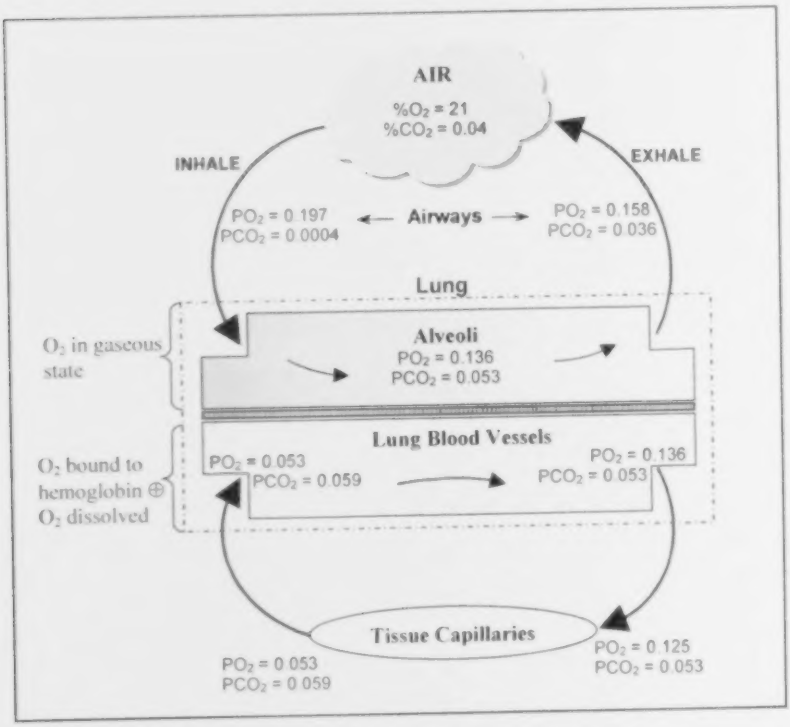

Figure 3. *Partial pressure (in ATA) gradient for the respiration process.*

3. **Gas Transport (of O_2 and CO_2):** the blood transports oxygen and carbon dioxide from the lung to the cells and from the cells to the lungs respectively (see Fig. 3). In the normal situation, 97% [2] of all oxygen in the blood is transported by hemoglobin in the red blood cells; the other 3% is dissolved in the plasma. Since hemoglobin is saturated with oxygen at sea level, high pressures add only dissolved oxygen in the blood. According to Guyton [2], at high pressures, the

same content of oxygen can sometimes be transported in the dissolved state as bound to hemoglobin.

In summary, supplemental oxygen is prescribed when the tissues of the body do not receive enough oxygen for their normal operation due to medical abnormalities involving one of the three above-described parameters. The intention is to raise the oxygen level in the lungs to offset deficiencies in one of these three parameters. The prescribed oxygen concentration varies between 24% to around 100%, depending on the clinical condition of the patient. Generally, the lower the patient's oxygen level, the higher the O_2 concentration required. However, there are physiological risks associated with its use.

2.2. Physiological Risks Associated with Supplemental Oxygen

A partial pressure of the breathed oxygen in the range of 0.21 (atmospheric conditions) to 0.5 ATA has been demonstrated to be safe for long periods [3]. If the oxygen partial pressure is too low (less than 0.16 ATA) the person will suffer from hypoxia and eventually die. On the other hand, oxygen becomes toxic to the body when breathed at increased partial pressure.

In this respect, pulmonary oxygen toxicity is likely to occur when the inspired oxygen partial pressure exceeds 0.6 ATA for prolonged periods. The most common signs and symptoms of this problem [4] are pulmonary symptoms (such as chest pain, dry coughing, lung irritation, chest tightness and dyspnia), headaches, dizziness, nausea, numbness in fingertips and toes, and a dramatic reduction in aerobic capacity. Breathing 100% oxygen at (or near) sea level gives a PO_2 of 1.0 ATA. Hamilton and Thalmann [4] clearly showed that continuous exposure for 300 min is a limit when PO_2 is equal to 1.0 ATA.

3. Oxygen Breathing Systems

Most oxygen breathing systems have certain basic components in common. A typical breathing system includes a gas supply, a breathing unit that includes an interface through which oxygen is administered to the patient, and some accessories.

3.1. Oxygen delivery systems

Breathing units are designed to deliver oxygen from the supply to the patients. Oxygen is administered to either breathing or non-breathing patients. But, the two patient types need distinct breathing delivery units. Indeed, a device for a breathing patient requires a respiration effort from the patient to move oxygen into the lungs. This device is obviously unsuitable for a non-breathing patient. Various companies, however, have recently provided a combined (two-in-one) breathing unit.

In the subsequent sections, O_2 delivery systems for breathing patients will be presented first followed by systems intended for non-breathing.

3.1.1. Breathing units intended only for breathing patients

Oxygen delivery systems for breathing patients can be open or closed circuit with continuous or on demand flows. The selection of a specific breathing unit type is determined by the oxygen treatment type (e.g., NBO or HBO), treatment location (pre- or in-hospital), O_2 concentration required, ventilation rate, tidal volume, respiratory condition and O_2 flow setting.

1. Nasal cannula:

The nasal cannula (Fig. 4 a) is most commonly used when a low oxygen concentration is sufficient to treat a patient. It is often chosen for its simplicity and patient comfort since it is attached to the patient's face (Fig. 4 b) by inserting the tips into nostrils; allowing the patient to eat, drink and have normal conversation. This device delivers an unpredictable oxygen concentration (< 40%) because of the possible inhalation of ambient air through the patient's mouth combined with the utilization of low O_2 flow rates (less than 6 litres per minute (L/min)). Oxygen can cause dryness of the skin and mucous membranes and become quickly uncomfortable for the patient [5]. In this regard, it is suggested that humidified oxygen should be provided when long treatments are expected [5].

2. Simple facemask:

The simple facemask is an oronasal mask with side ports (Fig. 5). It covers the patient's nose and mouth and is kept on by an elastic strap. This respirator has a mask volume of 100 to 300 ml and the fraction of the delivered oxygen

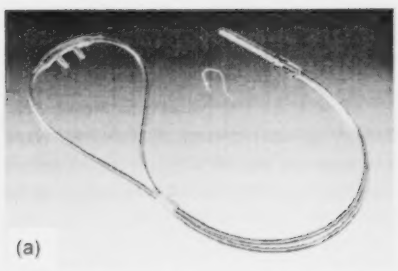

Figure 4. *Nasal Cannula: (a) from [6] and (b) from [7].*

(F_IO_2) is in the range of 0.35 to 0.55 with an O_2 flow of 6 to 10 L/min. It is recommended that oxygen flow rate be maintained higher than 5 to 6 L/min so as to prevent rebreathing of exhaled gas by the patient and, hence, CO_2 accumulation [8].

3. Venturi mask:

Primarily used in a clinical environment, this oronasal mask (Fig. 6) is designed on a mechanical venturi principle with the objective to increase O_2 flow rate into the mask and provide an accurate concentration of oxygen to the patient. Typically, this mask is calibrated to deliver up to six accurate F_IO_2 levels ranging from 0.24 up to 0.5 at various flow rates (e.g., 0.24 to 0.28 at 4 L/min and 0.35 to 0.40 at 8 L/min).

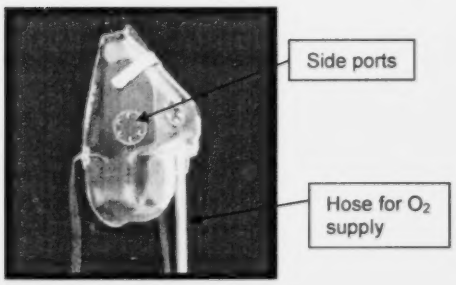

Figure 5. *Simple facemask [9].*

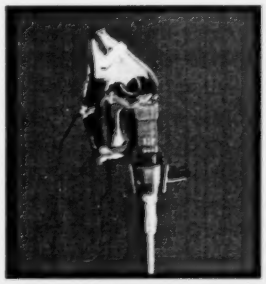

Figure 6. *Venturi mask [9].*

4. Partial rebreathing (or medium concentration) mask (PRM):

A partial rebreathing mask (PRM) is a simple facemask (similar to the mask shown on Figure 5) to which a breathing bag has been added as illustrated in Figure 7. It requires an O_2 flow rate high enough (at least 6 L/min) to maintain the reservoir bag continuously inflated [8]. The patient's exhaled gas can mix with the gas in the bag; thus, diluting inspired oxygen. At flows ranging from 6 to 12 L/min the system can provide 40 to approximately 60% oxygen concentration.

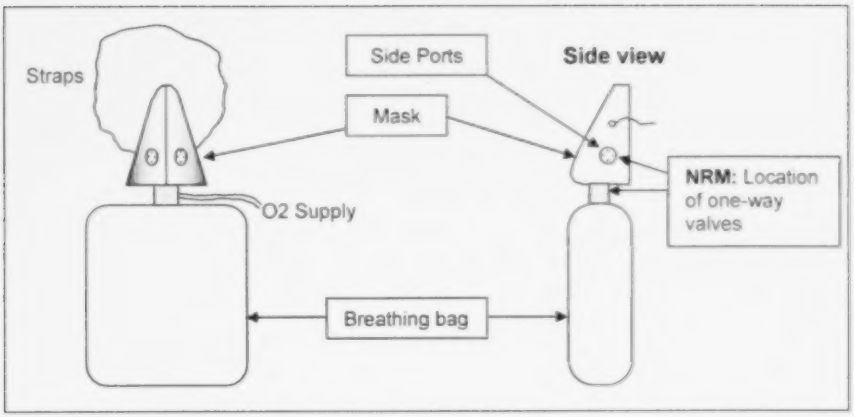

Figure 7. *Schematic of the partial rebreathing mask (PRM) and the non-rebreathing mask (NRM). In the NRM one-way valves are used to prevent rebreathing.*

5. Non-rebreathing (or high concentration) masks (NRM):

The non-rebreathing mask (also called NRM) (Fig. 8) is similar to the partial rebreathing mask (Fig. 7) except it includes a series of one-way valves. The first series covers one or both side ports of the mask to allow exhaled gas to escape without allowing a large amount of room air to enter. The other one-way valve is located between the breathing bag and the mask (Fig. 7) to prevent exhaled gas from returning to the bag. NRM is commonly used when high O_2 concentrations are required. Indeed, it can provide oxygen concentrations of up to 95% with an adequate mask fit in clinical environment. When compared to the previous masks a non-rebreathing mask allows a more accurate control of F_IO_2, making it one of the current choices for hypoxic patients and the most preferred in the field. However, high F_IO_2 can only be achieved with a tight seal between the mask and face and as long as oxygen flow rate is kept higher than 15 L/min [8 and 10]. When the patient needs only a medium oxygen concentration a minimum O_2 flow of 10 L/min is required to maintain the reservoir bag inflated.

Figure 8. *The non-rebreathing mask (NRM) [6,10].*

6. Tusk Mask:

The Tusk Mask consists of a partial rebreathing mask with two respiratory tubes, or tusks, placed on its sides (Fig. 9). The objective is to "entrain" from the tusks a portion of the exhaled gas which would be enriched with oxygen, reducing wasted oxygen. As illustrated in Figure 10, the Tusk mask can deliver higher O_2 concentration [11] (and arterial PO_2 [12]) when compared with PRM at the same oxygen flow rate (0, 5, 10, and 15 L/min) for a resting subject.

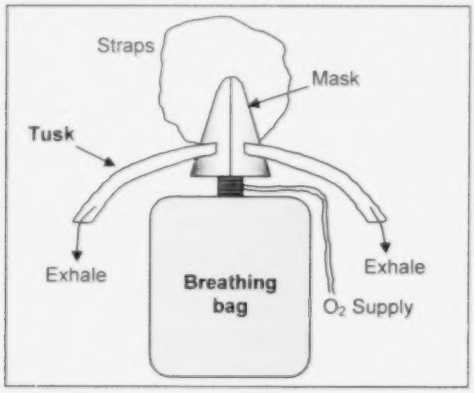

Figure 9. *Schematic of the Tusk Mask.*

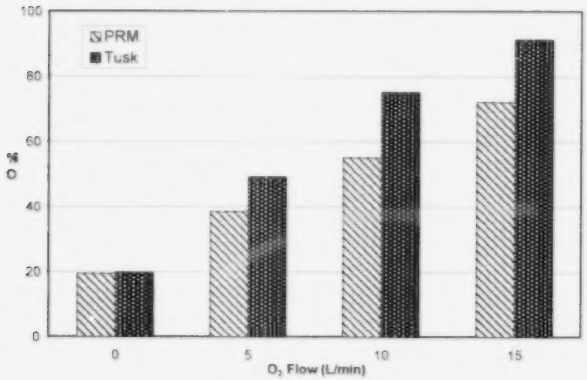

Figure 10. *Comparison of the Tusk Mask with PRM (data adapted from [11]).*

7. Oxygen tent:

This system is similar to a conventional tent and is used to deliver oxygen at higher level than normal to a patient in a bed. The tent is typically a clear plastic shell that covers the whole bed of an infant or the head and upper body of an adult. The Family Practice Notebook [13] categorized the tent

ineffective because of the unstable oxygen concentrations and the high flows needed to achieve even 30% oxygen concentration. However, it is better tolerated and useful for a patient that cannot wear or support facemasks or nasal cannula. Similarly, a smaller system called a face tent that covers only the lower face (nose + mouth) has been designed and used for the same purpose.

8. Oxygen treatment hood system (also called oxygen head tent):

The hood system (Fig. 11) is an open circuit, continuous flow oxygen delivery system. It includes an optical window, neck seal, and neck ring with O-ring and two ports for oxygen inlet and gas exhaust. Like most free flow systems, this device requires high flow rate (between 25 to 40 L/min) to maintain the hood inflation and, most importantly, remove carbon dioxide. Due to its simplicity and patient's tolerance and because oxygen supply is not an issue, the hood is one of the most preferred choices in hospitals and medical centres operating hyperbaric chambers.

Figure 11. *Hood system [14].*

9. Demand valve with mask:

Like a SCUBA regulator, the demand valve (Fig. 12) is designed to deliver oxygen to the breathing patient with minimal respiratory effort. Indeed, close to 100% O_2 is provided at the patient's inhale flow rate. The flow stops when the patient stops inhaling; thereby, minimizing oxygen consumption (when compared to the previous systems). Typically, for a resting patient, the flow rate provided by this system is equal to the patient's minute ventilation (approximately 5 L/min =10 breath/min X 500 ml) and can reach a peak of 160 L/min to accommodate the patient's respiratory situation. Designed to only operate when a regulated 50-psi oxygen supply is available, the demand system is one of the preferred methods of high concentration oxygen administration to a breathing patient in both NBO (Fig. 12a) and HBO therapy (Fig. 12b).

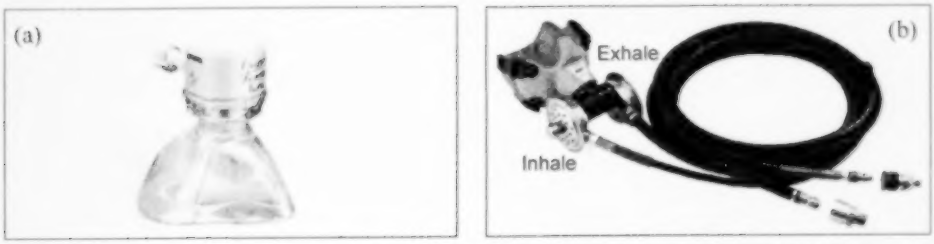

Figure 12. *Demand valve with mask; (a) for NBO therapy by O-TWO systems [15]; (b) for HBO therapy by Scott [16].*

10. Hi-Ox^{80}™ mask:

The Hi-Ox^{80}™ mask (Fig. 13) is a new open circuit continuous flow system [17-19]. It includes an oronasal mask with no side ports, a reservoir bag and a manifold (Figures 13 and 14) with three (3) one-way valves, one on each side (inhale and exhale) and the third valve that interconnects inhale and exhale. During expiration, the patient's exhaled gas escapes through the one-way valve to the atmosphere while the gas reservoir is filled with 100% oxygen. When inhalation begins, the inspiration valve opens so as to allow pure oxygen to be inhaled from the supply as well as from the reservoir bag. During this time, the one-way valve between the expiration and the inspiration sides remains closed. If the patient's minute ventilation exceeds the O_2 flow rate, the reservoir collapses which triggers the opening of the interconnecting valve. The last portion of inspired gas is therefore a combination of the last volume of expired air plus ambient air from the atmosphere.

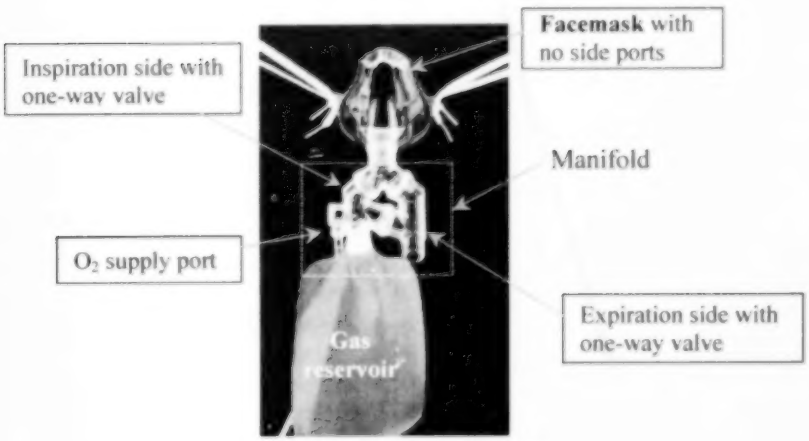

Figure 13. *The Hi-Ox^{80}™ mask [17].*

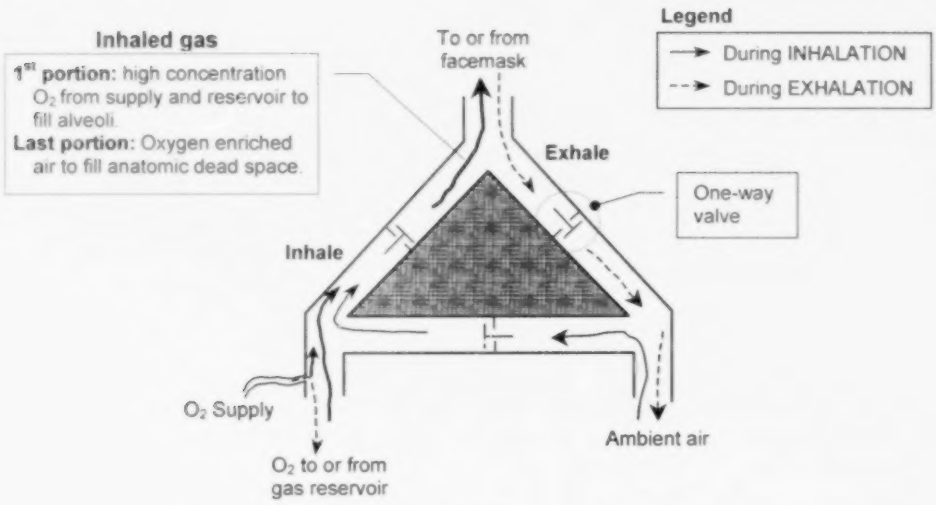

Figure 14. *Schematic of the Manifold of the Hi-Ox^{80}™ mask.*

In an experimental investigation, Somogyi *et al.* [18] compared the Hi-Ox^{80}™ mask, the simple facemask, the partial rebreathing mask and the non-rebreathing mask. They demonstrated that the Hi-Ox^{80}™ mask can provide more than 80% O_2 independently of minute ventilation or breathing pattern. For instance, when the subject is resting, this mask can deliver about 96% O_2 at a flow rate of 8 L/min (Fig. 15[3]); corresponding to an increase of about 75% if compared to the three other masks in the same study.

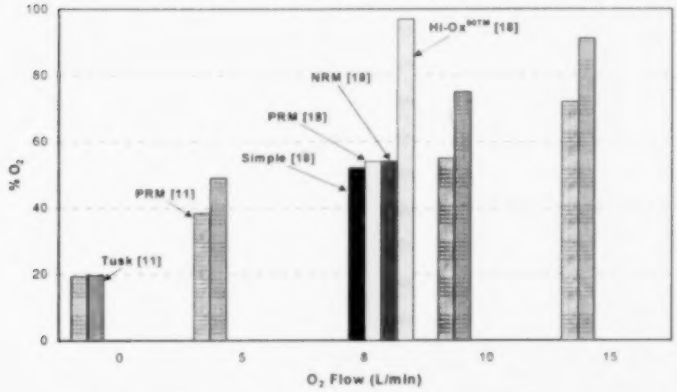

Figure 15. *Comparison of the Hi-Ox^{80}™ mask with the simple facemask, PRM and NRM at 8 L/min for a resting subject (data adapted from [11] for the Tusk mask and from [18] for the Hi-Ox^{80}™).*

[3] The data of the Tusk mask from [11] are included in Figure 15 for comparison.

11. Rebreather:

The rebreather is a closed circuit, continuous flow system. Instead of escaping to the atmosphere, the patient's exhaled gas is rebreathed after carbon dioxide is removed, and oxygen is replaced; increasing the O_2 concentration and the duration of O_2 supplies by eliminating wasted gas. Typically, a rebreather includes, as shown in Figure 16, a facemask, inhale and exhale hoses with a one-way valve each, a breathing reservoir bag, a carbon dioxide scrubber and an overpressure relief valve (also called positive end-expiratory pressure (PEEP) valve). Even though a rebreather can significantly increase oxygen therapy capability, especially when high oxygen concentrations are needed in field applications, it requires greater attention such as frequent purging and scrubber replacement to ensure appropriate operation. Recently, it has been demonstrated that a rebreather can be used in all types of oxygen therapy (NBO, hypobaric [20] or HBO [21]).

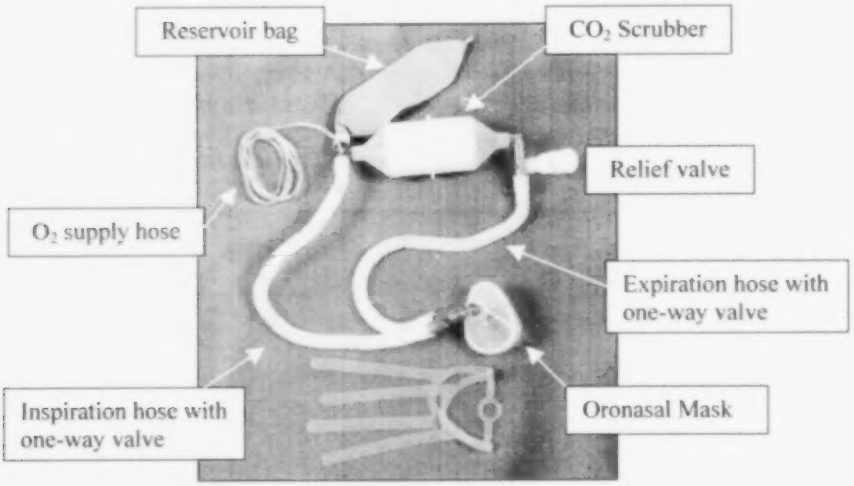

Figure 16. *The REMO$_2$™ rebreather [22].*

There are a wide variety of breathing units for breathing patients (Table 1), which suit a range of requirements for patient treatments. There are fewer options for non-breathing patients.

Table 1. Different types of oxygen delivery systems for breathing patients.

Breathing unit type	Circuit/ Flow	Delivered $\%O_2$	O_2 flow rate (L/min)	Breathing duration with a D tank [1]	Comment
Nasal cannula	Open/ Continuous	≤ 40	0.5 - 4	Up to 1h 30 min	Unpredictable F_iO_2. Needs to be connected to a control valve with a barbed outlet.
Simple facemask	Open/ Continuous	50-70	6 - 12	32 min – 1h 2 min	Unpredictable F_iO_2. Must be connected to a control valve with a barbed outlet.
Venturi mask	Open/ Continuous	≤ 50	Up to 15	26 min	Provides up to six accurate F_iO_2 levels. Clinical use only.
Partial rebreather mask	Open/ Continuous	35-60	6 to 12	32 min	Medium O_2 concentration. Must a minimum flow rate.
Non-rebreathing mask	Open/ Continuous	45-90	15	26 min	High F_iO_2 with a tight mask seal. Requires a minimum flow rate to keep reservoir bag full.
Tusk mask	Open/ Continuous	About 90	15	26 min	Provides higher F_iO_2 than non-rebreathing mask. Non-esthetical (mask +tusks).
Oxygen tent	Open/ Continuous	About 30	-	-	Useful for infant. Well tolerated by patient
Hood (or head tent)	Open/ Continuous	-	25-40	-	Requires a good neck seal. Requires high O_2 flows For NBO and HBO therapy.
Demand valve with mask	Open/ Demand	Close to 100	9-160[2]	2.5 – 42 min	Must be connected to a regulator with a DISS connector (50 psi). Requires a tight mask seal. For NBO and HBO therapy.
Hi-OX^{80}™	Open/ Continuous	≥ 80	8	50 min	Must be connected to a control valve with a barbed outlet. Requires a tight mask seal.
Rebreather	Closed/ Continuous	≥ 93	1	6h 30 min	Must be connected to a control valve with a barbed outlet. Requires a tight mask seal. Needs to be purged periodically. For NBO and HBO therapy.

(1) The capacity of a D tank is 425 litres (additional details in Table B1 in Annex B).
(2) Actual O_2 flow rate depends on breathing conditions of the patient.

3.1.2. Breathing units intended only for non-breathing patients

Non-breathing patients are unable to move oxygen from the breathing unit into their lungs and desperately need high concentration oxygen; therefore, special devices, called resuscitators[4], have been designed to provide ventilation without any effort from the patient. They can be operated manually or automatically.

1. Pocket Mask:

Also called a mouth-to-mask resuscitator, the pocket mask (Fig. 17) is an oronasal mask used by a rescuer or first responder to perform artificial respiration through a port without mouth-to-mouth contact with the non-breathing patient. It includes an oxygen inlet port so that constant flow oxygen combined with each breath delivered by the rescuer provides a high O_2 concentration. A low resistance one-way valve combined with microbial filter is installed on the main port to prevent expired gas from returning to the rescuer. The whole system, except the one-way valve, is reusable and easy to clean.

2. Bag Mask:

As shown in Figure 18, this device includes a facemask, ventilation bag, oxygen reservoir and PEEP valve. Nearly 100% oxygen is administered to the patient by squeezing the ventilation bag. This system is intended for use only by a well-trained person such as paramedics.

3. Pneumatic Ventilator:

This device uses oxygen pressure to ventilate non-breathing patients by forcing oxygen into the lungs. A number of demand systems that deliver oxygen on demand can be manually converted to a resuscitator by simply depressing a button (Fig. 19), allowing a non-breathing patient to be ventilated at 40 L/min[5].

Furthermore, other resuscitators can be completely automatic. They are pneumatically powered to deliver intermittent "breaths" to the patient. Figure 20 shows a three-in-one resuscitator manufactured by O-TWO systems [15] that combines automatic and manual ventilation with a demand system. For safety purposes, all these systems include a pressure relief system with an audible alarm that will trigger as soon as the pressure reaches 60 cm H_2O. Like the demand system, all ventilators operate only when a regulated 50-psi oxygen supply is available.

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[4] A resuscitator is a breathing apparatus used for resuscitation by forcing oxygen into the lungs of a person who has undergone asphyxia or arrest of respiration [23].

[5] As specified in the ISO standard: Resuscitators Intended for Use with Humans [24] and the 1992 Cardiopulmonary Resuscitation (CPR) Guidelines of the American Heart Association [25].

Figure 17. *Pocket mask from DAN [22].*

Figure 18. *Bag mask.*

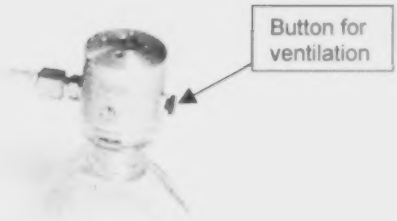

Figure 19. *Demand resuscitator [15].*

Figure 20. *Automatic resuscitator [15].*

3.2. Oxygen Supply

There are various methods to supply oxygen to a breathing unit and then to the patient:

1. **Compressed oxygen cylinder:** The most commonly used method is from a compressed O_2 cylinder, also called an oxygen tank. They are available in various sizes in steel, aluminium or composite materials. Their capacity varies from as little as 40 litres for NBO to approximately 6900 litres when a large amount of O_2 is required, for example in HBO. Large capacity tanks are usually made of steel and are usually associated with treatments done in fixed locations. Aluminium cylinders are produced from high strength aluminium alloy, contain a corrosion resistant interior surface, and are up to 40% lighter than some steel cylinders. Consequently, they are used most often for field and portable applications. The standard sizes presently used in first-aid O_2 therapy, for example, are the aluminium D (425 litres) or Jumbo D (640 litres) cylinders. The latter provides about 42 minutes of O_2 breathing at a flow rate of 15 L/min. Similarly, composite cylinders (carbon or Kevlar fibre-wrapped aluminium) are utilized for O_2 therapy as well. Not only are these tanks extremely lightweight, but they also can hold up to two times the amount of O_2 in an aluminium cylinder of comparable size. Therefore, they are highly suited to portable applications. Figure 21 shows available sizes of aluminium cylinders and Table B1 in Annex B highlights their detailed specifications and compares them to composite and steel tanks. Finally, in Canada, all cylinders must be inspected and hydrostatically tested in accordance with Transport Canada 3ALM requirements.

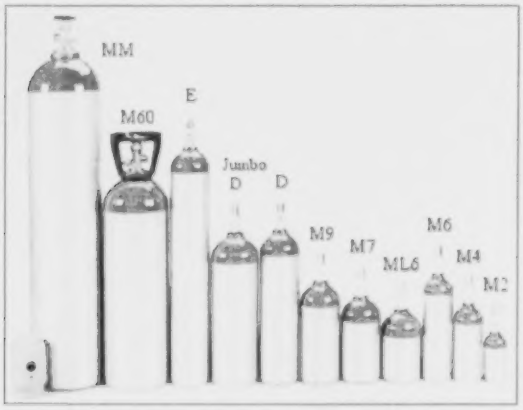

Figure 21. *Size range of aluminium oxygen cylinders [26].*

Every compressed gas cylinder comes fitted with an oxygen valve. A variety of valves with or without a handle[6] are available. The valves are normally made of

[6] A special wrench is required to open a valve that does not include a handle.

extruded brass. A regulator is connected to the valve to reduce the supply pressure (from about 3000 psig) to working pressures, nominally, 50 psi. There are two standard types of valve-regulator connection, CGA-870 (as seen in Figure 22) and CGA-540. The former, the most common, has two holes that mate to two pins on the regulator, and an "A" bracket and thrust nut to secure the regulator to the valve. The latter, more often used on large tanks (Cylinders MM and M60 in Figure 21), has threaded connections with the regulator.

Current regulators are made of aluminium or brass. Their outlets can have different configurations: a barbed outlet with a built-in control valve or two DISS-1240[7] connectors with check valves. Some regulators, like the one shown in Figure 22, have both outlet types (one barbed with a control valve and two DISS connectors). The function of the control valve, when integrated to the regulator, is to deliver a constant O_2 flow rate (commonly from 0 to 25 L/min) through the barbed outlet only to specific types of respirators, such as NRM, rebreathers, etc. The DISS outlets allow the regulator to be connected to a demand regulator, a resuscitator, or a manifold for multiple patients. In this case, the O_2 flow rate from the regulator reaches a maximum value of 180 L/min.

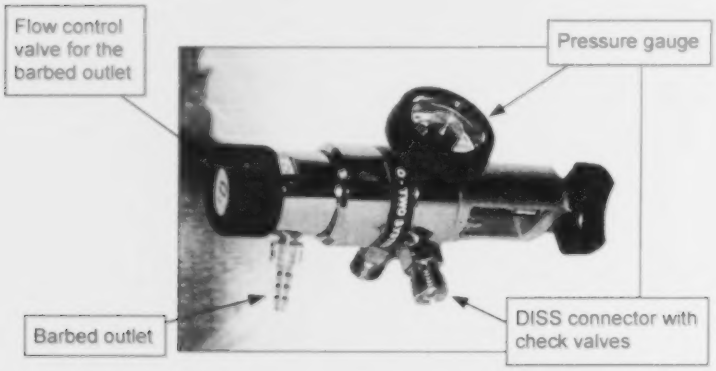

Figure 22. *A Regulator in CGA-870 configuration with 3 outlet connectors and a control valve [15].*

2. **Nitrogen Concentrator:** Commonly known as an oxygen concentrator, this system (Fig. 23) removes nitrogen from ambient air (inlet) and delivers oxygen-enriched mixed gas (approximately 96% O_2; 3% Argon and 1% others) at a flow rate that can reach 5 L/min [27-28].

   Figure 23 illustrates the process of producing oxygen-enriched air. Ambient Air is compressed by a centrifugal blower to a pressure of about 20 psi (1.4 bars) and

[7] The Diameter-Index Safety System (DISS) was developed by the Compressed Gas Association (CGA) to provide a standard for outlet connections. The dimensions of DISS outlets depend on the type of gas being used, preventing accidental connection of two different gas fittings. For example, DISS-1240 is exclusively used for oxygen.

then is cooled, and any water condensate is separated. The properties of chemical granules (typically, zeolite[8]) are used to select and adsorb nitrogen from the compressed air. This process is called adsorptive air separation [29]. The adsorbed nitrogen is then released and returned into the atmosphere. Two canisters of zeolite are used. One absorbs nitrogen while the second regenerates itself by releasing nitrogen to the atmosphere.

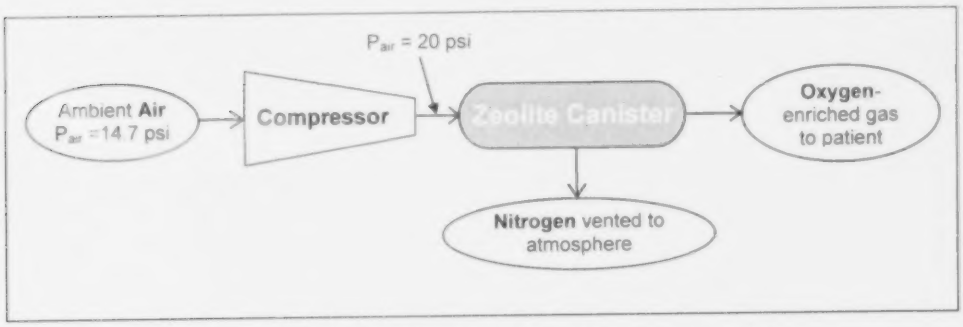

Figure 23. *Operation diagram of a nitrogen/oxygen concentrator.*

As shown in Table 2, current concentrators vary from large concentrators, e.g. the E-DOCS-120 [30], for remote (or field) hospitals to small portable battery-supplied units, such as the AirSep's LifeStyle O_2 concentrator [31], for individual patients.

Table 2. *Example of oxygen concentrators.*

Name	Performance	Dimensions *Height x Wide x Long (m)*	Weight *(kg)*	Power Supply	Battery duration *(hour)*
EDOCS-120 [30]	93 ± 3 % at 120 L/min	1.7 x 1.1 x 2.6	1590	-	Not applicable
PVOCS [32]	93 ± 3 % at 20 L/min max	0.59 x 0.63 x 0.60	65.9	VAC	Not applicable
Inogen One [33]	1 to 5 L/min	0.31 x 0.15 x 0.29	4.4[1]	Battery and VAC[2]	up to 3
Lifestyle™ portable oxygen concentrator [31]	90 ± 3 % at 4 L/min	0.14 x 0.18 x 0.41	4.4[1]	Battery and VAC[2]	1

([1]) Including battery

([2]) VAC: 110/220 volt and 50/60 Hz

[8] Zeolite is an adsorbent material that is formed by a network of microscopic holes [28]. According to Thorogood [29], zeolite granules have the property to select and adsorb nitrogen over oxygen and argon at ambient temperature and pressure.

3. **Chemical generator:** As opposed to the conventional supplies of gaseous oxygen, this system is a solid-state oxygen generator that uses a chemical reaction to produce O_2; thereby, eliminating the need of high-pressure oxygen storage particularly in airplanes and submarines. Also called oxygen candles or chlorate candles, the principal component of the chemical composition is sodium chlorate ($NaClO_3$). The oxygen is generated by the decomposition of the sodium chlorate during an exothermic reaction ($2NaClO_3$ + heat $\longrightarrow$ $2NaCl + 3O_2$). Figure 24 (a) shows an example of a solid-state O_2 generator produced by Scott aviation [34] for their Aviox® system (Fig. 24b). This system includes, in addition to the generator, a mask with a breathing reservoir bag and provides 4 L/min average continuous O_2 flow. Two formats of the Aviox® system are available (Fig. 24b) a 20 minutes single cartridge and 40 minutes dual-cartridge formats. Their specifications are detailed in Table B2 of Annex B.

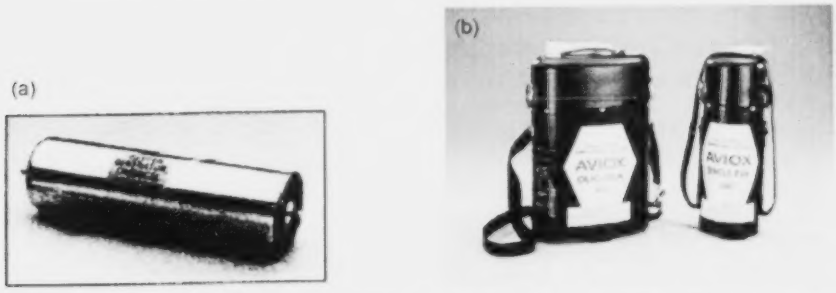

Figure 24. *The Aviox® system by Scott aviation [34]; (a) Its chemical oxygen generator; (b) Dual and single cartridge formats.*

Another type of chemical generator is the System O_2 ($SysO_2$) by *O2 Solutions inc.* [35] (Fig. 25). The oxygen is liberated from a biodegradable chemical reaction that takes place by combining water (H_2O) with sodium percarbonate[9] and manganese dioxide (MnO_2). This chemical reaction allows the separation of hydrogen from oxygen and releases the oxygen.

The system $SysO_2$ is intended for first-response situations. It is portable and includes a water bottle, a canister, a facemask, a carrying bag, and four refills (equivalent to 1 hour of refill) that contain two biodegradable chemical powders each. According to the manufacturer, pure oxygen (up to 99%) is delivered at 5 to 6 L/min for about fifteen (15) minutes per refill, eliminating the need and the hazards of pressurized oxygen cylinders. First-aid pure oxygen is ready to be delivered to a patient in 30 to 60 seconds.

[9] Sodium percarbonate is a chemical used to produce cleaning products. It is a compound of sodium carbonate and hydrogen peroxide that dissolves in water to liberate O_2 and provides bleaching and cleaning capabilities.

Figure 25. *The System O_2 ($SysO_2$) by O2 Solutions Inc. [35]*

An investigation by Pollock and Hobbs [36] to evaluate the performance of this system, demonstrated that the $SysO_2$ is less efficient than the pressurized oxygen systems with similar dimensions and weight. In contrast to O2 Solutions Inc. claims, the flow rate was limited (mean value ~ 3 L/min). The O_2 total yield was limited to 63 L compared to the claimed 75 to 90 L. In addition, this value is lower than the 250 L delivered by the M9 tank[10].

4. **Electrolytic oxygen/hydrogen generator:** this type of oxygen supply uses electrolysis to convert water into oxygen and hydrogen gases. It is commonly used as a life support system in space stations (such as the International Space Station) and certain US submarines. There are no field portable versions available.

[10] The specifications of the currently available pressurized O_2 tanks are presented in Annex B.

4. Discussion

The review covered various issues associated with oxygen therapy and delivery systems. The basis of oxygen therapy was first introduced including a description of the respiratory physiology and the risks associated with the use of oxygen. Components of an oxygen breathing system, such as oxygen supply, breathing unit including interface to the patient were then described.

In remote operations, oxygen therapy can be limited by either the type of oxygen supply or the delivery system. Currently, two types of O_2 supply are used, pressurized tanks or chemical generators. While the first type can be restricted or not allowed in certain locations (storage or weight concerns) or modes of transportation (e.g., fire hazard in airplanes), the latter is very limited in terms of gas consumption. The CF SAR Techs do not air transport or parachute oxygen cylinders. In this situation, the Scott Aviox® chemical oxygen generator is used. Consequently, the volume of oxygen available for remote treatment is very limited.

To estimate the efficiency of a system, a time density in $hr/(kg.m^3)$ has been computed and illustrated as a function of treatment duration (in hours). Basically, the higher the time density level at a given treatment duration, the higher the system efficiency. Figure 26 shows a comparison of chemical generators to systems using compressed cylinders. The time density of the Aviox® system is fairly high when the treatment duration is below one hour, but this system becomes highly inefficient with prolonged treatments.

For systems using compressed cylinders, two types of delivery unit for oxygen therapy are available, open and closed. With open circuit oxygen delivery systems the patient exhales gas to the atmosphere. They can be constant flow or on-demand. Open circuit, constant flow delivery units, such as the simple facemask and the non-rebreathing mask (NRM), have been designed to be simple. Because their loose mask allows the entrainment of air with the inhaled oxygen, the inspired O_2 fraction varies in the range of 0.24 to 0.60 with flow rates between 6 and 15 L/min (360 to 900 L/hr). The simple design and low cost make this type of masks the most commonly used in medical centres where oxygen supply is not an issue, but they are impractical for use in remote locations because of their low efficiency in terms of oxygen consumption. The time density of NRM with a DD composite cylinder is the lowest of all oxygen delivery systems in Figure 26.

With on-demand systems, oxygen is delivered only when the patient inhales. In fact, the negative pressure generated in the mask, which requires a breathing patient and a tight mask-face seal, triggers the oxygen flow. This O_2 flow stops when the inhale ends; thereby, improving O_2 consumption and concentration in comparison to the continuous flow oxygen systems. Indeed, the time density of this mask is higher than NRM (Fig. 26). Moreover, high concentration oxygen (> 90%) can be achieved at the patient's minute ventilation (about 5-10 L/min for a person at rest). Presently, the on-demand system is commonly used to treat diving casualties in remote areas, but its

time density significantly decreases with extended treatment duration (beyond one hour).

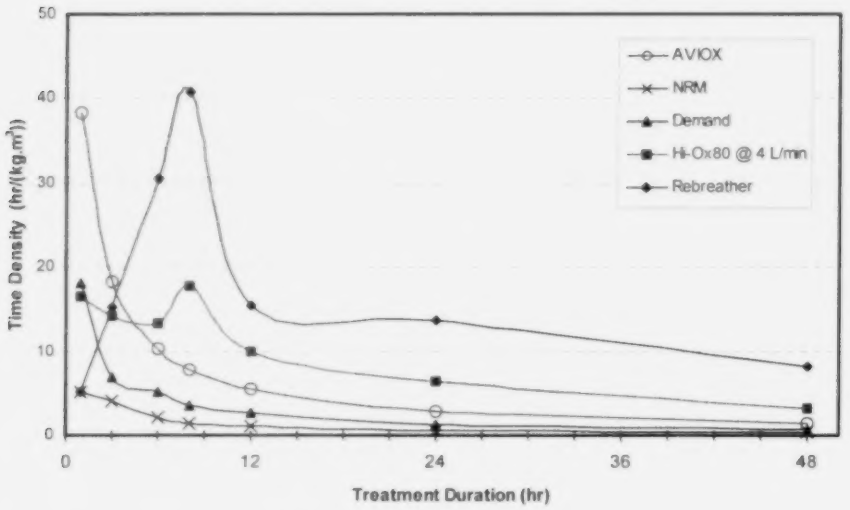

Figure 26. *Time density as a function of treatment duration of common O_2 breathing systems. The DD composite tank was selected for breathing units requiring compressed O_2.*

The VIASYS Hi-Ox^{80TM} mask is an open circuit breathing system that is anticipated to be efficient in delivering oxygen therapy. Indeed, it has been demonstrated [18] that the delivered O_2 fraction can exceed 0.90 at a flow rate of 8 L/min independently of the breathing pattern. Furthermore, it has been reported [37] that, with small modifications to the system (i.e., a rebreathing bag integrated on the exhale side of the mask manifold), 100% O_2 can be achieved at 4 L/min, thereby, increasing its time density over the on-demand and NRM masks (Fig. 26). This will most likely provide efficient O_2 therapy in remote operations only if O_2 is available. Figure 26 also shows that the time density of this system reaches a peak at 8 hours. This is due to the type of the O_2 supply considered in this study. The DD composite tank is very light and when integrated with the Hi- Ox^{80TM}, only three tanks are required for a treatment duration of 8 hours, which optimizes the utilization of the Hi-Ox^{80}/DD tank ensemble.

The oxygen rebreather is a closed-circuit system. The gas that is being expired is rebreathed after carbon dioxide is removed and consumed oxygen replaced. With less than one litre per minute (or < 60 L/hr) of oxygen use, this system is considered the most efficient. The time density, as shown in Figure 26, is the highest when the treatment exceeds 4 hours. The maximum is reached at 8 hours because of the low oxygen flow required by the rebreather and the type of the O_2 tank considered in the study. Only one DD composite tank is used with the rebreather for a treatment of 8 hours, thereby increasing the efficiency of the rebreather/DD tank ensemble.

The rebreather system can deliver oxygen with F_IO_2 as high as 1.0, which makes this system, if compressed oxygen is available, the preferred choice in providing O_2 therapy in remote locations. Operation of a rebreather is more complex than open-circuit systems. The rebreather requires extra components (e.g., CO2 scrubber, rebreathing bag, relief valve), which involve special attention and supervision by an attendant. For instance, the CO_2 scrubber must be replaced after a certain period of utilization (i.e., between 5 and 8 hours). Moreover, because of the build up of nitrogen into the system, frequent purging of the circuit is necessary, typically, by increasing the O_2 flow rate from 0.5 to 8.0 L/min. This increases the effective consumption of oxygen.

Most of the currently available breathing systems for oxygen therapy in remote operations use compressed cylinders. When the compressed tanks are not available or allowed, the only commercially available effective oxygen source is the chemical generator. It would seem natural that the rebreather/chemical generator ensemble would have a high time density. Unfortunately the chemical generator flow rate cannot be controlled; therefore, it is not practical for use with a rebreather without some sort of large reservoir. On the other hand, the chemical generator could be combined with the Hi-Ox^{80TM}.

Smaller and lighter O_2 concentrators can be developed [31, 33 and 37] to deliver high concentration oxygen (> 92%) at a flow rate of 4 L/min for 5 hours with one battery charge. This could be a worthwhile alternative to pressurized cylinders or chemical generators in administering NBO therapy. Indeed, it would be possible to integrate portable concentrators to delivery units like a rebreather or Hi-Ox^{80TM}to significantly improve safety during storage and transportation and provide extended capability to treat patients in remote areas. The time density of O_2 delivery units will be greater with the use of concentrators. Figure 27 clearly shows that the time density of the Hi-Ox^{80TM}/concentrator ensemble is not only the highest when compared to the other oxygen supplies but also remains high with prolonged treatment durations. On the other hand, the effect of the concentrator on the rebreather is less significant (Fig. 27). This is mostly due to the large weight and volume of the rebreather system. While the rebreather uses the volume of three Hi-Ox^{80TM} masks, its weight is one order higher (2 kg for the rebreather versus 200 g for the Hi-Ox). Moreover, the CO_2 scrubber of the rebreather (which weighs 1 kg) must be replaced every 8 hours, thereby increasing the weight of the rebreather system for prolonged treatments.

The two systems currently commercially available that could possibly be paired with an O_2 concentrator are the VIASYS Hi-Ox^{80TM} mask and the DAN REMO2* rebreather. Since these two breathing systems are new and their performance relatively unknown, it is recommended to evaluate their performance and reliability for CF field operations.

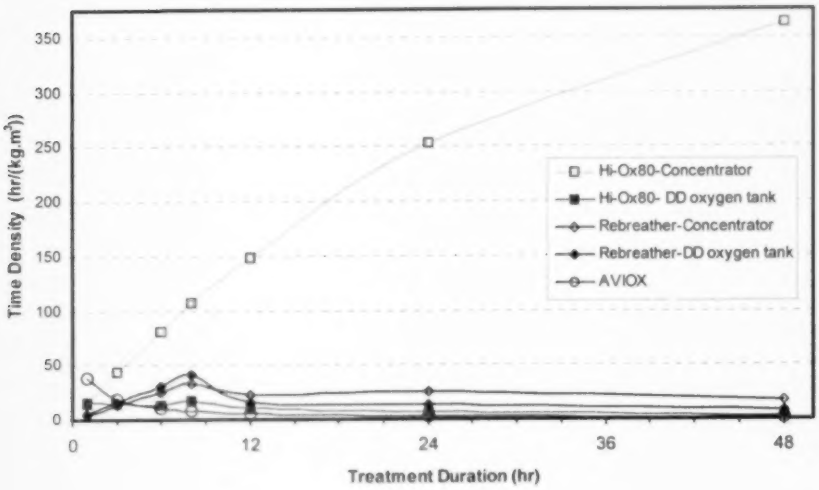

Figure 27. *Effect of the use of a concentrator.*

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Annex A : Partial pressures in the respiratory system

Table A1. *Partial pressures and concentrations of gases from inspiration to expiration (adapted from [2]).*

Component	Atmospheric air		Inspired air		Alveolar air		Expired air	
	mm Hg	*%*	*mm Hg*	*%*	*mm Hg*	*%*	*mm Hg*	*%*
N_2	597.0	78.62	563.4	74.09	569.0	74.87	566.0	74.47
O_2	159.0	20.84	149.3	19.67	104.0	13.68	120.0	15.79
CO_2	0.3	0.04	0.3	0.04	40.0	5.26	27.0	3.55
H_2O	3.7	0.50	47.0	6.18	47.0	6.18	47.0	6.18
Total	760	100	760	100	760	100	760	100

Table A2. *Partial pressures (in mm Hg) of oxygen and carbon dioxide in the lung blood before and after gaseous exchange and in the tissue capillaries before and after metabolism.*

Component	Lung Blood		Capillaries	
	Before	*After*	*Before*	*After*
O_2	40	104	95	40
CO_2	45	40	40	45

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Annex B : Specifications of Oxygen Supplies

Table B1. *Specifications of oxygen cylinders.*

Cylinder		Oxygen Capacity		Service Pressure		Cylinder Length		Cylinder O.D.		Cylinder Weight	
Type	*Size*	*feet*^{3}	*litre*	*psi*	*bar*	*in*	*mm*	*in*	*mm*	*lbs.*	*Kg*
Aluminium	M60	62	1738	2216	153	23.00	584	7.25	184	21.7	9.86
	E	24	680	2015	139	25.63	651	4.38	111	7.9	3.59
	Jumbo D	23	640	2216	153	16.30	414	5.25	133	8.1	3.68
	D	15	425	2015	139	16.51	419	4.38	111	5.3	2.41
	M9 (C)	9	255	2015	139	11.88	276	4.38	111	3.7	1.68
	M7	7	198	2015	139	9.18	233	4.38	111	3.3	1.5
	ML6 (M6A)	6	165	2015	139	7.68	195	4.38	111	2.9	1.32
	M6 (B)	6	165	2216	153	11.59	294	3.20	81	2.2	1.0
	M4 (A)	4	113	2216	153	8.40	213	3.20	81	1.6	0.73
	M2	1.4	40	2216	153	5.37	136	2.50	63.5	0.7	0.34
Composite	EE	49.5	1377	2216	153	20.4	519	6.60	167	7.3	3.3
	DD	26	717	3000	207	13.5	343	4.30	109	3.7	1.68
	DD	19	533	2000	138	13.5	343	4.30	109	3.7	1.68
Steel	K	241	6702	2265	154	56.00	1422	9.00	228.6	132.7	60.33

Table B2. *Specifications of the Scott Aviox® Portable Oxygen Breathing Units (adapted from [34]).*

Type	Operating Range (°C)	Dimensions (cm)	Weight (kg)	Estimated Price (US $)
Single-Pak	-17.8 to 50	36.8 H x 14 W x 11.4 Depth	1.95[1]	625.00
Duo-Pak	-17.8 to 50	37.6 H x 24.9 W x 12 Depth	3.75[1]	969.00
Generator Replacement Kit	-17.8 to 50	5.7 Diameter x 19 Height[2]	0.79	150.00

([1]) Includes generator and mask.

([2]) Estimated.

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List of symbols/abbreviations/acronyms/initialisms

ATA	Atmosphere absolute
CF	Canadian Forces
CGA	Compressed Gas Association
CO_2	Carbon dioxide
CPR	Cardiopulmonary Resuscitation
DAN	Divers Alert Network
DISS	Diameter Index Safety System
DND	Department of National Defence
DRDC	Defence Research and Development Canada
EDU	Experimental Diving Unit
E-DOCS	Expeditionary Deployable Concentration System
F_IO_2	Fractional inspired oxygen
H_2O	Water
HBO	Hyperbaric oxygen therapy
ISO	International Organization for Standardization
L/min	Litre per minute
mm Hg	Millimetre of mercury
MnO_2	Manganese dioxide
N_2	Nitrogen
NBO	Normobaric oxygen therapy

NRM	Non-rebreathing mask
NaCl	Sodium chloride
$NaClO_3$	Sodium chlorate
NIF	New Initiative Fund
O.D.	Outer diameter
O_2	Oxygen
PCO_2	Partial pressure of carbon dioxide
PEEP	Positive end-expiratory pressure
PO_2	Partial pressure of oxygen
PRM	Partial rebreathing mask
PVOCS	Patient Ventilation Oxygen Concentrating System
psi	Pound square inch
psig	Pound square inch gage
SAR	Search and Rescue
SCUBA	Self Contained Underwater Breathing Apparatus
$SysO_2$	System O_2 by O2 solution inc.
Techs	Technicians
°C	Degree Celsius
$\%O_2$	Oxygen concentration
$\dot{V}_A$	Alveolar ventilation
$\dot{V}_D$	Dead space ventilation
$\dot{V}_E$	Minute respiratory volume (or minute ventilation)

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14. ABSTRACT

(U) The Experimental Diving Unit (EDU) of Defence RDCanada – Toronto has received support from the Search and Rescue (SAR) New Initiative Funds (NIF) to develop and recommend a system for providing oxygen to multiple victims. Current breathing systems used for oxygen therapy are highly inefficient in the consumption of oxygen, especially when a mass casualty incident is involved. Treating more survivors means more oxygen must be transported which increases weight, volume and risk. There are many breathing systems on the market for oxygen therapy. These respirators vary in the concentration and quantity of oxygen effectively delivered to the patient. The present report defines and describes oxygen therapy, including an introduction to human respiratory physiology and a review of the characteristics and capabilities of breathing systems that are the most commonly utilized to provide oxygen. The purpose is to identify promising solutions for the Canadian Forces search and rescue operations.

(U) L'Unité de plongée expérimentale (UPE) de R &D pour la défense Canada – Toronto a reçu l'appui du Fonds des nouvelles initiatives du Secrétariat national Recherche et Sauvetage (SNRS) afin de mettre au point et de recommander un système permettant d'administrer de l'oxygène à de nombreuses victimes. Les systèmes de respiration actuels utilisés en oxygénothérapie sont extrêmement inefficaces sur le plan de la consommation d'oxygène, en particulier en cas d'incident entraînant des pertes massives. Pour traiter un plus grand nombre de survivants, il faut pouvoir transporter une plus grande quantité d'oxygène, ce qui contribue à accroître le poids, le volume et le risque. Un vaste éventail de systèmes de respiration sont offerts sur le marché pour l'oxygénothérapie. Les différences entre les appareils concernent la concentration de l'oxygène et la quantité d'oxygène effectivement administrée au patient. Dans le présent rapport, nous définissons et décrivons l'oxygénothérapie, nous présentons des notions élémentaires de physiologie respiratoire humaine et faisons un survol des caractéristiques et des possibilités des systèmes de respiration qui sont les plus couramment utilisés pour administrer de l'oxygène. Nous nous proposons d'identifier les solutions prometteuses pour les opérations de recherche et sauvetage des Forces canadiennes.

15. KEYWORDS, DESCRIPTORS or IDENTIFIERS

(U) Oxygen Therapy; Normobaric; Hyperbaric; Oxygen breathing apparatus; Oxygen breathing system; Oxygen mask; Oxygen supply; Oxygen concentrator; Oxygen resuscitator; Physiology of respiration

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